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# Submarine Sonar System Concepts for Littoral Waters

## (Preliminary Unabridged Version)

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# Submarine Sonar System Concepts For Littoral Waters

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## Summary/Abstract

This article describes submarine sonar concepts for use in littoral waters. Included are sonars for use in, on, or with an innovative submarine sail. The new sail is envisioned for submarines beyond the New Attack Submarine (NAS), although some of the sonar concepts could be backfit to NAS, 688, or Seawolf class. The new concepts are a result of a "clean slate" look at future submarine sonars for littoral waters. Certain of these concepts will undoubtedly be accepted and others altered or discarded as more formal, detailed cost and effectiveness studies are conducted.

***"What we anticipate seldom occurs; what we least expect generally happens."***
Benjamin Disraeli[2]

## Background

With the end of the Cold War, the U.S. Navy laid out a dramatic new strategy. The essence of this strategy was documented in late 1992 in " ... From the Sea".[3] The strategy was finalized after extensive senior (military and civilian) naval staff participation during fiscal year (FY)[4] 1992. At this time the Navy was also completing its FY 1994 budget for submission to the Department of Defense (DoD) and Office of Management and Budget prior to submission by the President to the Congress in early 1993. Because the strategy was well thoughtout, "well staffed,"[5] and had broad support, it survived the transition from the Bush to Clinton administration and has been adopted by Secretary of the Navy John Dalton[6] and

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1 The author is located at the Naval Undersea Warfare Center (NUWC), Division Newport (DIVNPT), Detachment New London, Submarine Sonar Department, 39 Smith Street, New London, CT 06320. The views expressed here are those of the author.

2 Quoted by RADM Thomas Brooks in *U.S. Naval Institute Proceedings,* March 1994.

3 S. O'Keefe, F. B. Kelso II, and C. E. Mundy, Jr., " ... From the Sea: Preparing the Naval Service for the 21st Century," Navy White Paper, September 1992, reprinted in *U.S. Naval Institute Proceedings*, November 1992, Vol. 118, No. 11, pp. 93-96.

4 A list of acronyms is provided in Appendix A.

5 By "well staffed," we mean the strategy was presented to the naval leadership as "completed staff work" ready for signature; it was bold and visionary, yet it had consensus support and was defensible at the DoD and Congressional levels.

6 J. H. Dalton, "Leadership for the Sea; Power From the Sea," *Surface Warfare*, November/December 1993, pp. 4-7. More recently, in the August 1994 issue of the *U.S. Naval Institute Proceedings*, Secretary Dalton stated that "We embrace the concept of ' ... From the Sea' and applaud the direction that it takes the naval service." He continues, saying that we need to begin work on a new framework with " ... From the Sea" as the foundation and starting point. In the same issue Chief of Naval Operations Admiral J. M. Boorda, U.S.N., states that " ... From the Sea" remains an extremely important document. We need to update and expand it, however." In an October 1994 interview with *Sea Power* Admiral Boorda, commenting on rewriting the Navy's strategy paper, " ... From the Sea." stated "I approved the final draft of the rewrite. ... one of the draft titles is 'Forward ... From the Sea'". Before the Naval Submarine League on June 16, 1994, Secretary Dalton

Assistant Secretary of the Navy Nora Slatkin.[7] While this strategy had been public for some 2 years, the significance of this "paradigm shift"[8] became clear to the Undersea Warfare Research & Development community while executing the FY94 budget, defending the FY95 budget and preparing the FY96 budget.

Having contributed to the collapse of the former Soviet Union, the United States now enjoys the freedom of the open ocean. As "... From the Sea" states, "With the demise of the Soviet Union, the free nations of the world claim preeminent control of the seas ... " Moreover, for the foreseeable future, the focus of the U.S. Navy is to project power ashore *from the sea*. The coastline areas are referred to as "littoral" areas. They are often, but not always, shallow water areas.[9] In these areas of the world, the DoD, through organizations such as the Advanced Research Projects Agency (ARPA), is beginning to envision new submarine sail concepts for submarines beyond the New SSN (NSSN), the Navy's New Attack Submarine (NAS). The Naval Undersea Warfare Center (NUWC), Division Newport (DIVNPT) is tasked by ARPA through Electric Boat in Groton, Connecticut to conduct initial submarine sail studies. Beyond this effort, NUWCDIVNPT is developing sensor suites for littoral warfare; some of these are located on a new innovative submarine sail and others exploit a new sail. As will be described, these new sonar suites are needed because "(m)astery of the littoral should not be presumed. It does not derive from command of the high seas. It is an objective that requires our focused skills and resources."[10]

This article discusses submarine sonars for use in littoral waters, including their relationship to innovative submarine sail concepts. Sonars are vital to a submarine's success, but the paradigm shift that requires submarines to be fully integrated participants in the battle force means that submarine sonars must become more than just devices located on submarines. While the main objective of a new submarine sail is to improve communications,[11] sonar performance is dependent on sail design. A new sail has the potential to improve submarine sonar in two ways. First, sonar performance of sail sensors can be improved. Secondly, with High Data Rate (HDR), real-time communications, sonar can be linked to offboard sensors

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reported (about the expanded new framework): "One of the goals of this strategic framework is to more fully discuss the role of our Submarine Force in littoral operations and forward presence."

7 N. Slatkin, "Undersea Warfare: An Acquisition Strategy to Meet New Dangers," *Sea Technology*, January 1994, pp. 30-33.

8 What follows is an example of a "paradigm shift." For instance, because accurate time- keeping was key to accurate navigation (in particular, determining longitude), the revelation of how to keep accurate time was a capital offense in the British Navy. Many years later, digital quartz technology replaced mechanical devices, making accurate time available at low cost; indeed thousands of people lost their jobs making finely crafted watch main springs.

9 Note shallow water and very shallow water mean different things to different readers. To acousticians, shallow water is often defined in terms of wavelengths or bottom interactions; for others, it simply means a particular depth. For example, divers without underwater breathing apparatus think of 20 feet as deep, but for a submarine with a nominal 30-foot hull diameter, 20 feet is very shallow. At 100 Hz, 150 feet is only three wavelengths, so an acoustician might well consider 150 feet shallow.

10 O'Keefe *et. al., op. cit.*

11 Communications is not provided to improve the quality of life aboard a submarine but rather to provide a seamless connectivity with the task force comparable to that of a surface ship in support of a wide variety of missions.

and assets with cuing for improved sonar and combat system performance.[12]

## Submarine Operations in the Littoral Environment

The nuclear-powered submarine offers stealth, agility, and endurance for joint[13] littoral operations. It can maintain a forward presence and be first on scene. The submarine can be covert and nonconfrontational. It is an ideal naval platform for providing the National Command Authority (NCA) with indications of upcoming hostilities. It complements other national assets by providing warnings of such activities as ships leaving port, underwater mine laying, the presence of underwater minefields and intercepted naval and coastal message traffic. This is the Indications & Warnings, or I&W, mission. With proper communications suites (especially HDR antennas), the submarine can transmit intelligence back to the NCA and receive detailed tasking for the next phase of operations.

With speed and stealth, the submarine is well positioned to covertly insert commandos or so-called Special Operations Forces (SOF) *from the sea.*[14] The SOF, headquartered in Tampa, Florida, operates as a fourth branch of the DoD: Army, Air Force, naval forces, and SOF.[15] The SOF is a truly joint command with components from the three services, including the Navy's Sea Air Land commandos (SEALs). Navy SEALs can be inserted and extracted from submarines using surface launched Combat Rubber Raiding Craft, subsurface launched wet Swimmer Delivery Vehicle, or by subsurface launched dry, long-range Advanced Swimmer Delivery System (an electric drive mini-submarine) now being developed.[16] The SOF ashore can provide intelligence and laser designation of key defensive radars and command and control targets. During insertion and extraction of Navy SEALs, the submarine could be close to the surface and to the shore. This proximity might place the submarine in shallow water, say, less than 20 or 30 fathoms (120 or 180 feet)[17] at

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12 To a lesser extent, sonar performance of non-sail acoustic sensors can be changed (perhaps improved) by changing (improving) hydrodynamic flow around the submarine, thereby reducing flow noise and distortion. We speculate that changes would be mainly to hull arrays but could include both existing and future sensors, such as, sphere, towed arrays including future MultiLine Towed Arrays (MLTAs), the Wide Aperture Array (WAA), the Advanced Mine Detection System (AMDS), Noise Augmentation Units (NAUs), noise monitors and ice-penetration sonars.

13 By "joint" we mean triservice, i.e., Army, Air Force and Navy/Marine Corps. In contrast, we use the term "combined" to mean multiple nations.

14 SOF, not now a regular part of the submarine complement, rendezvous with or are pre-embarked when inserted by submarine. Later in an operation, submarines can be used to extract SOF.

15 See John M. Collins, "Special Operations Forces," CRS Report for Congress 93-697S, July 30, 1993.

16 "Warm and Dry: Mini-Sub Will Bring SEALs In From The Cold", *Armed Forces Journal*, April 1994, p. 46. More sophisticated operations could allow SOF ASDS launch from a surface ship far off shore, rendezvous with a forward deployed submarine for a final mission update, mission deployment, and return to another submarine. The October 13, 1994 issue of the NL Day reported a $69.8 million contract award to Westinghouse Electric Corporation for a 60-ton ASDS boat.

17 For those who question whether the submarine will operate in shallow water, ADM (then VADM) William Owens stated on May 11, 1993: "Thirty or more days before the landing is scheduled, the submarine could already be there in the seventy or eighty feet of water."

speeds of less than 3 knots (nautical miles/hour) for prolonged periods. During these near-stopped, shallow-water operations involving stopping and maneuvering (including backing down),[18] towed arrays will not be deployed and the needed vertical aperture of multiline towed arrays (MLTAs) will not be available. Moreover, the near-surface position of the hull and WAA sonars (above the layer) will limit sonar performance to acoustic sources above the layer and severely restrict performance against sound sources (such as adversarial submarines) below the layer. These environments and scenarios favor offboard sensors close to the source because of propagation loss;[19] because of the multiple acoustic rays in the shallow water waveguide, they also favor vertical sonar arrays that deploy below the layer and form narrow beams that can capture vertically separated acoustic rays while simultaneously discriminating against noise. Of course, detailed studies and analysis must be conducted to assess the cost and effectiveness of innovative sonars designed to operate in such complex environments.

If operations require,[20] the submarine will be ideally suited to (covertly) initiate a Submarine Launched Cruise Missile (SLCM) attack *from the sea*. Such a SLCM land attack can disrupt enemy shore-based anti-air radar, as well as command, control, and communications centers, thereby clearing the way for joint carrier-based air attacks and land-based U.S. Air Force stealth air attacks. However, the complexities of such attacks require large volumes of data (called air tasking orders) that can take hours to be downloaded to the submarine "shooters." To be an effective player in this mission, the submarine must be able to receive large volumes of message traffic, including last minute updates.[21] As envisioned, this will force the U.S. submarine to keep a large sail receiving antenna exposed above the water, potentially decreasing submarine stealth. Further, the "shooter" will be constrained to a fixed geographical "launch basket." Clearly, these key joint operations will place new loads on the submarine combat (or command and control) systems and restrict the maneuverability of the submarine; restriced maneuverability, in turn, limits depth excursions and lead-lag legs historically used for target motion analysis making rapid localization sonar extremely important. Such constraints will force changes in methods for layered ship self-defense, Anti-Submarine Warfare (ASW) and Anti-Surface Warfare (ASUW) operations and restrict the

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18 Similar maneuver restrictions might also apply during the strike mission.

19 Offboard sensors might be linked back to the submarine by HDR comms made possible by a new sail. VADM George W. Emery, U.S.N. and COMSUBLANT, stated the following on May 10, 1994: "Communications is a critical area for integrated operations with submarines and other forces, joint and allied. The key problem here is achieving the higher data rates and compatibility with the rest of the fleet because of the limitations of submarine antennas. We must be able to communicate with anyone in a seamless and automatic fashion."

20 This will be the case if the U.S. joint (or Allied combined) forces do not yet have air superiority or if the submarine is the first on station and the requirement is immediate.

21 As VADM George W. Emery, U.S.N. and COMSUBLANT, stated on May 10, 1994: "Our (referring to the submarine force) ability to strike targets ashore must also keep pace with the rest of the Navy ... Communications is a critical area for integrated operations with submarines and other forces, joint and allied. The key problem here is achieving the higher data rates and compatibility with the rest of the fleets because of the limitations of submarine antennas." Alternative less stealthy communications concepts (using smaller, lower data rate antennas) might allow the submarine to query a national data base, thereby seeking out the specific information needed. While the smaller antenna might be less detectable, the query would require an active transmission that could be detectable.

sonar performance if only conventional, submarine-based sonar sensors are relied upon.

Littoral operations will have profound implications on future submarine sonar systems. Sonar and combat systems must be enhanced to operate effectively in littoral waters, and this must be accomplished in an increasingly tight fiscal environment. In addition, deep-water, open-ocean dominance must be retained. This involves conventional and evolving sensors, processing, displays, training, and command and control for ASW and ASUW.[22]

## Submarine Sonar Forcing Functions

Three forcing functions for submarine sonar when the submarine operates in the littoral include:[23] intelligence gathering, the environment, and submarine posture.

First, intelligence gathering will require that the submarine[24] (1) sonar act as a sensor for the Joint Task Force (JTF) Commander[25] and that (2) sonar/combat system integrates and fuses received signals from: (a) offboard sensors such as Unmanned Underwater Vehicles (UUVs),[26] (b) bistatic active sonar,[27] and (c) national

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22 We need to continue to improve so that we retain our ability to move ships, troops and supplies from U.S. ports across the open ocean enroute to littoral waters.

23 Of course, they include other forcing functions, too, beyond the scope of this article. For example, U.S. sonars must take into account counterdetection range by a potential adversary. This, in turn, would include concern for our radiated signal levels and our target strength, including sail shape and reflectivity. Unlike cold-war, open-ocean operations, we will now also be concerned with the radar cross section of a sail exposed in littoral waters.

24 We use the term "requirements" here in an informal or technical sense and propose to further examine such requirements together with other more formal ones.

25 While acting as a sensor for the JTF may not be a primary mission, there will be a role for the submarine to report back to the JTF what it has encountered both to provide information vital to launching an assault and to provide information for other submarines that will enter the area. This information might include what has been learned about the undersea environment, including minefield disposition. Robert Holzer reporting in the April 11-17, 1994, issue of *Defense News* states that "the Navy's $320 million Mine Warfare Plan ... calls for integrating submarines into mine operations and upgrading submarine combat systems to boost their mine-warfare capabilities." He goes on to quote RADM Charles Horne as saying that "Submarines, through their stealth, add a tremendous capability in covert surveillance. ... Here is a force that is already paid for, that is increasingly operating in much, much shallower water." He also quotes Marine Maj. Gen. Harry Jenkins as saying on March 29, 1994 that "We want to use the attack submarine with improved sonar to go through and map out the mines ... . We want to locate where the mines are and use that (information) to exploit gaps."

26 RADM William P. Houley stated on June 16, 1994 that "UUVs will be a huge force multiplier for SSNs." He went on to saythe following: "The UUV will be of great importance to the Joint Task Force Commander whose willingness to sail a nuclear reactor into shallow, potentially mined waters, can be expected to be a lot lower than the submarine's brave commanding officer." VADM George W. Emery, U.S.N. and COMSUBLANT stated the following on May 10, 1994: "In many cases, we need to field equipment and get it to the fleet as soon as possible, such as an operational unmanned underwater vehicle (UUV). ... Minefield detection and mapping is a real problem ... The solution is a UUV that will allow us to stand off, and won't put our people or ships at risk."

27 To retain stealth, a forward-deployed submarine listens passively for encoded active sonar returns that have been transmitted by remotely deployed acoustic sources.

(satellite) assets with downloaded (minefield) intelligence. Note, for intelligence gathering involving minefields, localization accuracy drives submarine sonar (size and location) requirements. For example, accurate determination of underwater mine depth nominally requires a sonar with vertical aperture. Furthermore, minefield intelligence requires (two-way) communications and connectivity with JTF and perhaps NCA.

Secondly, environmental conditions in the littoral vary widely as a function of space (i.e., geographical location) and time (of day and season). For example, sound propagation is dominated by temperature versus depth profiles.[28] Storms, typically in the winter, tend to mix up the top part of the water column causing an iso-thermal layer that profoundly affects sound propagation. On a daily basis, biological scatterers tend to feed at different times of day, moving about within the water column changing reverberation levels that impact active sonar performance. Poor environmental conditions limit acoustic signal reception (due to downward-refracting acoustic rays, steep grazing angles and numerous bottom and surface interactions[29] between the source and receiver). Moreover, poor environmental conditions drive the need for (1) offboard deployable sensors and (2) cuing. Stated differently, environmental conditions may be so poor in littoral waters that the only way to sense objects of interest is to be cued by external controllers or offboard sensors closer to the objects of interest.[30] Of course, poor environmental conditions are a double-edged sword in that such conditions provide added acoustic stealth for our submarines. Also, note, satellite-based radar may provide future forward-deployed submarines with a common tactical picture.

Thirdly, submarine operational posture[31] will limit the submarine maneuverability normally required for optimal sonar and target motion analysis performance. Moreover, this posture requires NAUs during training and selected operations.[32] Submarine operational posture requires low target strength under water and also requires low radar cross section in air. Further, this posture requires good open-ocean sonars to get to littoral waters; this requires well-behaved flow around submarine sensors so that spherical and wide aperture arrays, as well as other sensors, perform well. To be investigated are the impact of operating near the surface in the openocean (enroute to the littoral) to receive HDR communications with mission planning updates, air tasking orders, and tactical pictures common to the JTF.[33]

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28 S. K. Mehta and G. C. Carter, "Underwater Acoustical Signal Processing," *The Electrical Engineering Handbook*, (R. C. Dorf, Ed.), CRC Press, Boca Raton, FL, ISBN, 0-8493-0185-8, 1993.

29 Each interaction results in a significant loss that depends upon sea-state for surface interactions and sediment type (mud, sand, rock, etc.) for bottom interaction.

30 It is noteworthy that Offboard sensors is on the July 1994 COMSUBLANT/COMSUBPAC list of high priority Command Technology Issues.

31 By "operational posture," we include operating with NAUs activated, operating near the surface, and requiring JTF control for coordinated SLCM Strike and Special Operations insertion and extraction.

32 NAUs augment or raise own-ship radiated levels, thereby enhancing training against submerged submarines.

33 In addition to receiving mission updates in the open ocean enroute to littoral waters, other issues include submarine crew comfort in a high-sea state when operating near the surface with the sail exposed for communications and the obviated need for long-range sonar detections with centralized cuing and control.

## Technical Requirements[34]

At the technical level, we envision at least the following submarine sonar requirements. Of course, we must make certain that these systems include processing, displays and integration into the combat and control system and that out-year budgets will support training, operations and maintenaince of these sonars. So anticipating the validation of formal requirements, we speculate that they will include requirements for:

(1) a mine avoidance sonar with a large (vertical or horizontal or both) aperture for accurate mine position estimation,[35]

(2) offboard sensors (e.g., UUVs, the Deployable Acoustic Sensor System, DASS; or Advanced Deployable System, ADS) with connectivity/linkage to the submarine and high-gain aperture,

(3) a permanent NAU in the sail, to avoid continuous cross-decking costs,[36]

(4) noise monitor sensors in several locations, including in and on the sail for acoustic stealth,

(5) AN/WQC-2 on the sail for acoustic communications call-up,

(6) AN/WLR-9 or AN/WLY-1 on the sail for 360-degree intercept receive capability,

(7) a sphere and WAA for detection and rapid localization, and

(8) a chin-mounted AMDS, below and aft of the bow for underwater mine detection, (horizontal) bearing estimation, and bottomed mine detection, classification and localization, and

(9) TAs and MLTAs for slow- and high-speed low frequency passive (and bistatic active) operation

## Submarine Sonar Advanced Concepts[37]

We have grouped advanced concepts for submarine sonars operating in the littoral into three areas: (1) sonars on, in, or deployed from a new submarine sail, (2) sonars exploiting a new innovative sail with HDR communications, and (3) other sonars not on, in, or from a new sail. Several of these shipboard sonars are "crudely" sketched in figure 1; important offboard sensors will be shown in a later figure. While figure 1 depicts both only a single vertical line array above the sail, this could be a vertical multiline system. Note also that while figure 1 depicts both a vertical array deployed from the sail and a Cylindrical Sonar System (CYSS) below the submarine, for some operations only one of these array systems would be deployed at a time. If the submarine were submerged and hovering, near the bottom, the CYSS couldn't be deployed below the boat, rather a (single or multiline) vertical acoustic array would be deployed

34 As earlier, we use the term "requirements" here in an informal or technical sense. There are additional formal and informal requirements, including the processing and display of information from the sensors described in this section as well as from nonacoustic sensors.

35 Vertical arrays are useful for vertical mine localization accuracy. Our current assessment is that a vertical array on the sail is workable, inside the bow for mine avoidance appears to be unworkable or very high risk; while a vertical array affixed to the bow has some risk (due to a variety of factors including anticipated interference to the spherical array's reception).

36 Combat control systems can be automated to virtually eliminate the chances for inadvertent activation of a permanently installed NAU.

37 This section contains just released patent pending and/or data previously designated as acquisition sensitive.

upward from the submarine sail.[38] If the submarine had its sail exposed for communications or SOF operations and were traversing at low speed, it would lower (one or more) CYSS volumetric array(s) below the submarine; this would provide the needed vertical (and some horizontal) aperture and position some sensors below the layer. As envisioned, this array would be lowered about 100 feet below the keel, or even deeper with spacers or affordable very-thin optical arrays. In water shallower than 100 feet (plus hull diameter), the cylindrical array would only be partially deployed. For ranging three CYSS arrays might be used.

Sonars being considered in or from a new submarine sail include (1) a Mills cross or "T" array (with a full horizontal and vertical aperture)[39] with an unimpeded vertical acoustic array in or on the sail (versus the riskier alternative of a high-frequency array in or on the bow) and (2) acoustic sensors in a vertical line from a submerged submarine to a communications buoy. See the computer-generated concept in figure 2; note this figure

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38 An alternative option would be to deploy a vertical acoustic array from another cavity of the submarine rather than from the sail. To reject interferences, sophisticated interarray processing methods employed between the line and other sensors or multiple vertical lines could be deployed with sophisticated signal processing.

39 Of course, the value of such a sail array with vertical extent lies mainly in its capability to accurately estimate underwater object (mine) height; it is ineffective for mine avoidance when the sail is out of the water for communications and littoral operations. Also, its downward- looking effectiveness in the water is reduced when placed too far aft. The alternative horizontal chin-mounted AMDS array has good forward looking capability and bearing discrimination capabilities but its depth accuracy capability is limited by its vertical aperture. For mine avoidance, the AMDS chin array appears adequate.







is the output of an iterative process and the sketch here is one early iteration in that process.[40] The aft (left) darkened section of figure 2 is a cargo hatch for SOF equipment. Also, while not shown in figure 2, other undersea warfare systems, including communications and self-defense have been taken into consideration (by NUWC engineers K. Lewis and R. Gebelein) in selecting the location for the submarine sonar sail concepts shown here. The "T"-shaped mine avoidance sensor with its vertical aperture would allow accurate depth determination when the submarine is submerged. Of course, when the sail is exposed in the air, the sail sonar would not be used to transmit or receive underwater signals, but it might receive in-air acoustic signals of air- or patrol-craft.

Sonars exploiting a new innovative sail with HDR communications include submarine sonar and combat systems linked by satellite, fiber optics, or RF communications to sonobuoys; DASS and ADS arrays; ocean surveillance assets; national (imaging) assets Tactical Exploitation of National Capabilities (TENCAP);[41] and Hamlet Cove (Beach Comber). An artist's cartoon of these offboard sensors is shown in figure 3.

Finally, sonars for use during littoral operations include the CYSS with 9 vertical arrays, each having 111

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40 Beyond the scope of our work here is the consideration of additional undersea warfare systems and platform systems including radar and air acoustic intercept systems. However, we refer the interested reader to D. G. Browning, "A Comparison of Sound Propagation in Air and Shallow Seawater Under Summer Conditions," NUWC-NPT Reprint Report 10,659 of 16 June 1994 for a discussion of the use of air acoustics for threat detection in the poor environment conditions found in shallow water in summer.

41 See page Navy-32 N94-147 of DoD FY1994 Small Business Innovation Research (SBIR) Program Solicitation 94.2.

sensors deployed below the submarine.[42] This sonar is illustrated in figure 4. The rudder design shown protruding from the water would be changed and the sail shape would be smoothed to be more like that shown in figure 2. A Navy patent is being prosecuted for the CYSS submersible sensor system invention.

## Submarine Sonar Advanced Demonstrations[43]

We envision the need to demonstrate some of our advanced concepts (related to submarine sonar developments that are tied to a new innovative sail). For convenience, we group the submarine sensor research, development, test & evaluation demonstrations into three areas: (1) sail specific sensors, (2) sensors that exploit new innovative sails, and (3) other littoral sensors.

First, sail specific acoustic demonstrations include the following: (1) Mills cross or "T"-sail array beam patterns, (2) NAU transmission through new low radar cross section sail materials, and (3) a vertical acoustic line array from a submerged submarine sail to a floating Radio Frequency (RF) communications buoy. The demonstration treats both handling and acoustic performance.

Secondly, demonstrations to exploit new sail HDR communications include a submarine link from external sources to a prototype sail and then to NUWCDIVNPT's land-based sonar and combat system laboratories. These laboratories include the Submarine Sonar Development Evaluation Complex (SSDEC) and the Combat System Evaluation Laboratory (CSEAL) land-based test sites. In these demonstrations, we would link the sail by satellite and RF communications to ocean surveillance (e.g., ADS) assets, sonobuoys, and NCA, and then link the prototype sail to land-based test sites.

Third, other littoral and sail alternative demonstrations include (1) "T" or mills cross array, but now on the bow (instead of the sail), (2) CYSS with 9 arrays of 111 sensors each (Navy patent pending), and (3) as a possible alternative to a sail-mounted or "T" array consideration of a vertical mine-hunting transmit array that telescopes out of a vertical stowage tube.[44]

## Summary

Four key points must be summarized in discussing the new submarine sonars that will be needed to operate effectively in littoral waters.[45] First, we need to continue to improve sonars so that we retain our ability to move ships, troops, and supplies from U.S. ports across the open ocean enroute to littoral waters. We note that sail shape will affect both our underwater target strength and flow characteristics around the sail. This, in turn, will impact both ship handling and sonar self-noise. Secondly, we need mine detection, mapping, and avoidance sonars (some sail mounted) to penetrate littoral waters. Thirdly, we need offboard acoustic sensors and assets. Fourth and last, we need connectivity to offboard sensors and national cuing and command assets.

Environmental conditions are such that several submarine sonar challenges exist to meet the Navy's new strategy focused on projecting power *from the sea.*

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42 This is a notional array of either 999 sensors or the thin optical equivalent. An independent performance assessment and demonstration of array gain would be conducted before settling on the final array configuration. The CYSS includes an active adjunct located on the depressor.

43 This section contains just released patent-pending data and data previously designated as acquisition sensitive.

44 While this configuration gives up strike capability; it should be investigated for total warfare system cost and effectiveness since if the submarine can't penetrate or avoid a minefield its platform effectiveness is diminished

45 Not listed in priority order.

Because of the profound shift in re-ordering the Navy's missions, we have prepared recommendations for development will be needed to assess and demonstrate sonar performance in littoral waters.

## Recommendations

Submarines operating in the littoral will require improved sensors and connectivity. It is recommended that the following effort be performed:

- Develop and validate models of environmental conditions critical to submarine sonar operation in key littoral areas.
- Conduct studies and analysis that assess the cost and effectiveness (including performance and contribution) of various submarine sonar sensors in achieving joint and combined missions.
- Continue to develop submarine-based mine-avoidance sonars, some of which will be forward-looking chin arrays. Depending on the results of assessments, some will be mounted on the submarine sail, such as a "T" array (with full vertical and horizontal aperture) with an unimpeded upward and forward look. They will likely be in or on the sail (versus the riskier alternative of a vertical array in or on the bow).
- Develop and demonstrate offboard acoustic sensors that are linked to the submarine sonar and combat control system, such as sonobuoys, the cylindrical DASS depicted in figure 3, the ADS arrays, and ocean surveillance assets. Some offboard sensors will be on or connected to UUVs.
- Develop and demonstrate HDR real-time connectivity to offboard sensors, national (imaging) assets, and TENCAP for improved cuing.
- Develop and demonstrate the performance of two CYSSs each consisting of 9 vertical (thin optical) arrays, of 111 sensors each deployed below the submarine for own-ship defense when the submarine operates at low speed, near the surface, in littoral waters.
- Develop and demonstrate a vertical sonar[46] that reels into the sail or submarine. Such a nominally vertical line array of acoustic sensors, depicted in figures 1 and 2, and would deploy from a submerged submarine to a floating communications buoy while the submarine loiters near the bottom. Loitering can be during I&W missions, awaiting SOF insertion or extraction and while awaiting SLCM land attacks. If assessment studies require strong interference rejection, a multiline vertical cylindrical array or sophisticated interarray signal processing would be employed.
- Continue to develop the deep water sonars necessary for (1) transiting to shallow water, (2) dominating deep-water littoral undersea battle space, and (3) (incidentally) retaining open ocean dominance.[47]

## Acknowledgement

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46 Such an array would serve a self-defense role in the littoral.

47 This is particularly important in light of the lessons of history summarized in the Benjamin Disraeli quote: "What we anticipate seldom occurs; what we least expect generally happens." More recently in the August 1994 issue of the *U.S. Naval Institute Proceedings*, Admiral J. M. Boorda, U.S.N., states the following: "History tells us that our enemies will use many forms of threats and violence to challenge our national interests. If we do not proceed carefully and preserve a range of combat capabilities, we surely will provide the opening that others can -- and will -- exploit."

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## Appendix A: List of Acronyms

ADS, Advanced Deployed System
AMDS, Advanced Mine Detection System
ARPA, Advanced Research Project Agency
ASW, Anti-Submarine Warfare
ASUW, Anti-Surface Warfare
CSEAL, Combat System Evaluation and Analysis Laboratory
CYSS, Cylindrical Sonar System
DASS, Deployable Acoustic Sensor System
DIVNPT, Division Newport
DoD, Department of Defense
FY, Fiscal Year
HDR, High Data Rate
I&W, Indication & Warning
JTF, Joint Task Force
LFA, Low Frequency Active
MLTA, Multi-Line Towed Array
NAS, New Attack Submarine
NAU, Noise Augmentation Unit
NCA, National Command Authority
NSSN, New SSN
NUWC, Naval Undersea Warfare Center
RF, Radio Frequency
SBIR, Small Business Innovative Research
SEALs, Sea Air Land (SOF Commandos)
SLCM, Submarine Launched Cruise Missile
SOF, Special Operations Forces
SSDEC, Submarine Sonar Development Evaluation Complex
TA, Towed Array
TENCAP, Tactical Exploitation of National Capabilities
UUV, Unmanned Underwater Vehicles
WAA, Wide Aperture Array

Figure (1) Sketch of advanced submarine sonar for littoral waters

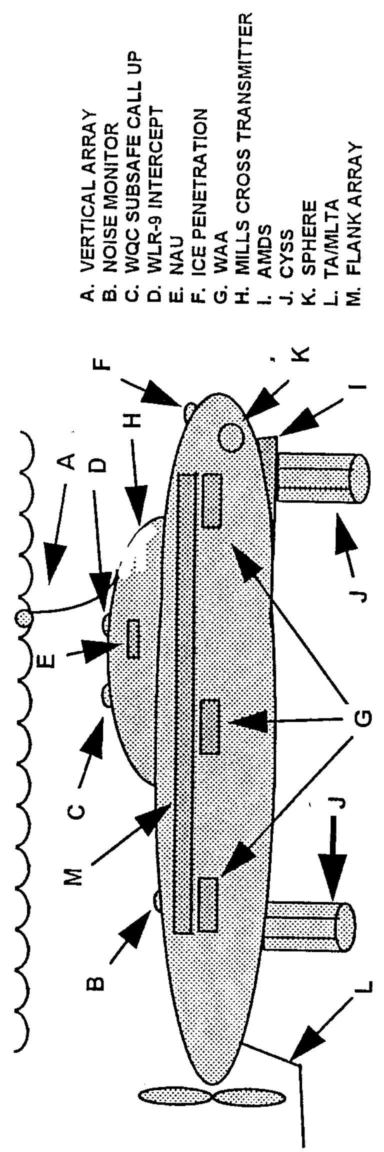
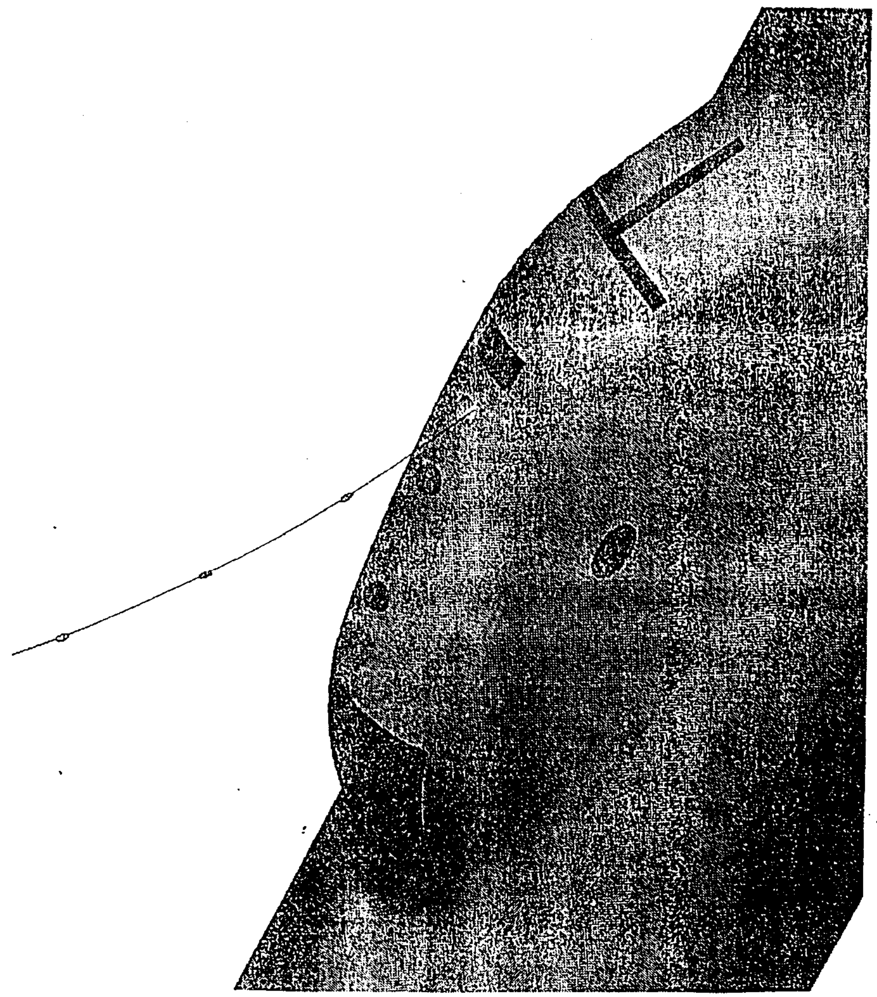



Figure (2) Computer-drawn submarine sonars on an innovative sail



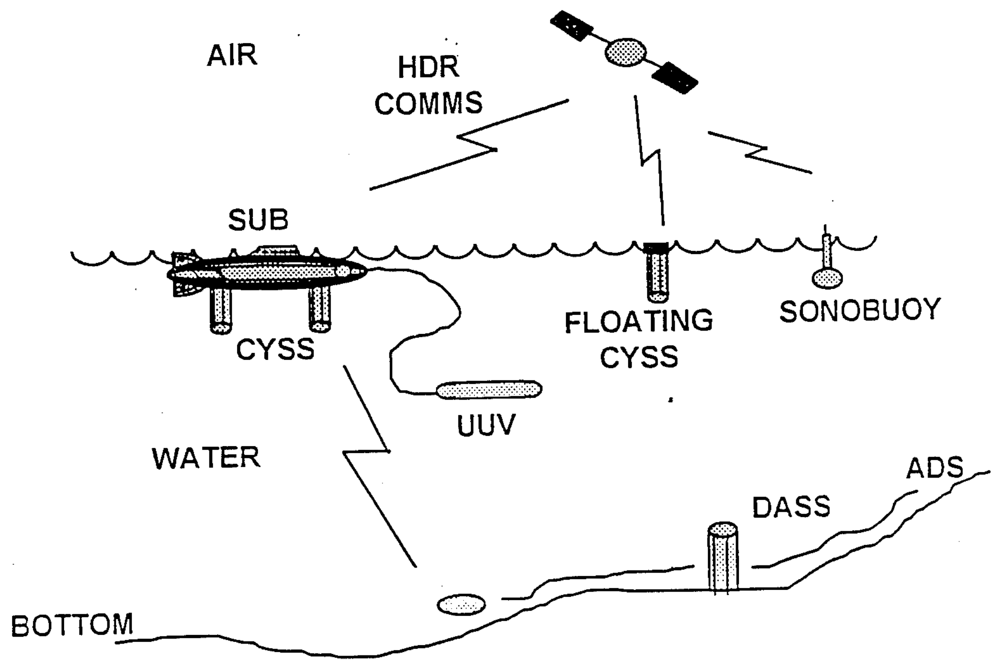



Figure (4) Cylindrical Sonar System (CYSS) for littoral operations

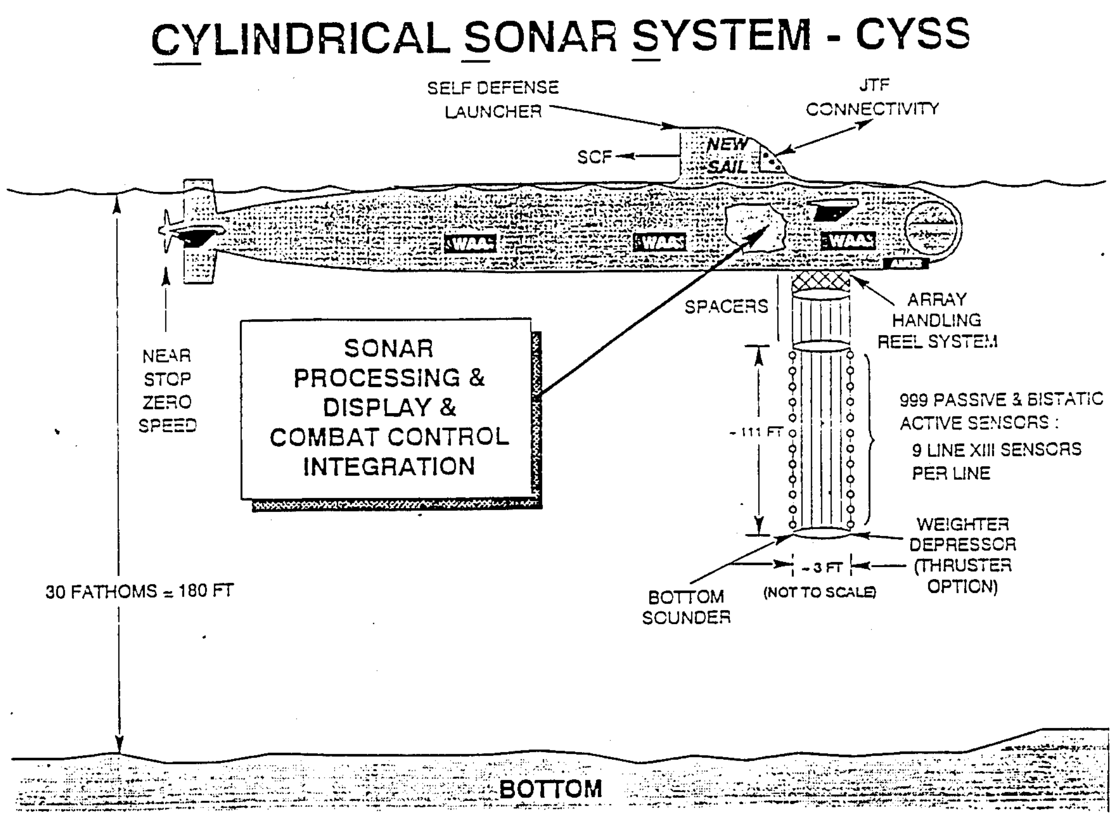



Figure (3) Off-board submarine sonar systems for littoral operations